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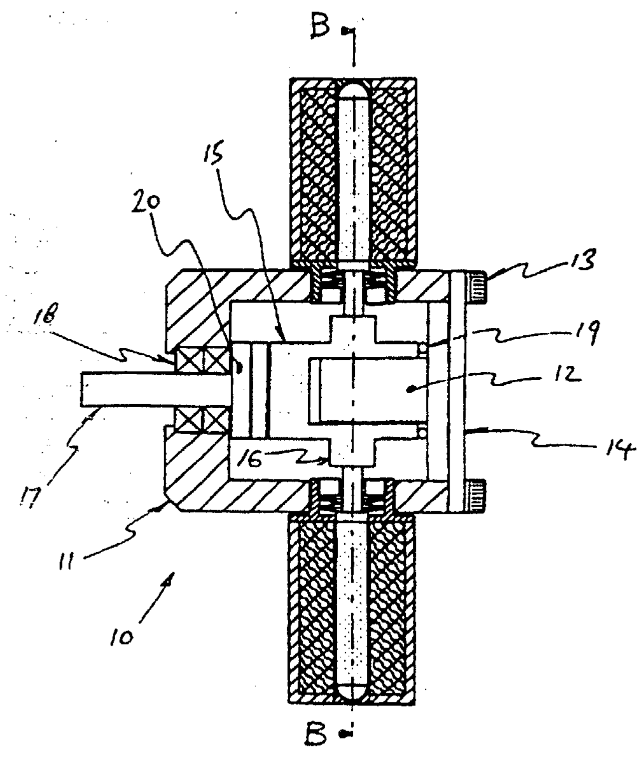
(54) Title: MOTOR

(57) Abstract

A motor is disclosed including a first member (12) having a convex surface (25), and a second member (15) having a concave surface (26) engaging the convex surface; wherein one of the members constitutes a stator and the other of the members constitutes a rotor, and wherein the curvature of the convex surface is greater than the curvature of the concave surface, and drive means (21) for driving the rotor such that the point of engagement between the convex and concave surfaces moves whereby the rotor rotates relative to the stator.



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"MOTOR"

Technical Field

This invention relates to a motor.

This invention has particular application to a motor wherein linear motion is converted to rotary motion.

Summary of the Invention

In one aspect this invention resides broadly in a motor including:-

a first member having a convex surface, and

a second member having a concave surface engaging the convex surface;

wherein one of the members constitutes a stator and the other of the members constitutes a rotor, and wherein the curvature of the convex surface is greater than the curvature of the concave surface, and

drive means for driving the rotor such that the point of engagement between the convex and concave surfaces moves whereby the rotor rotates relative to the stator.

The drive means can be any means that generates a force and displacement. The drive means could for example have a camming action. It is preferred that the drive means includes a linear actuator for driving the rotor. As used herein the expression "linear actuator" refers to actuators which have a linear motion. The linear motion may be reciprocating or vibratory motion.

In one embodiment the first member is the stator and the second member is the rotor. In this embodiment it is preferred that the stator is a fixed mandrel and the rotor is a sleeve or external rotor ring adapted to rotate about the fixed mandrel.

Alternatively in a second embodiment the second member is the stator and the first member is the rotor. In this embodiment it is preferred that the stator is a fixed sleeve and the rotor is a sleeve or internal rotor ring adapted to rotate within the fixed sleeve.

The motor may include damping means for damping eccentric movement of the rotor. In a preferred embodiment the damping means is an Oldham coupling or the like.

Alternatively, the motor may include constraint means for constraining movement of the stator to a plane perpendicular to the axis of the rotor whereby the rotor does not move eccentrically during rotation and the stator orbits relative to the rotor.

In this embodiment the stator can be a sleeve and the rotor a mandrel adapted to rotate within the sleeve. Alternatively, the stator can be a sleeve and the rotor also a sleeve adapted to rotate about the stator sleeve.

It is preferred that the drive means is adapted to apply force to the rotor or the orbiting stator at a plurality of locations. Thus the drive means may comprise a plurality of linear actuators. Preferably the drive means comprises at least three linear actuators.

The linear actuators may apply a force to the rotor or the orbiting stator in other than a radial direction but it is preferred that the linear actuators are substantially radially directed and substantially symmetrically spaced relative to the rotor. Thus the linear actuators may be radially directed and symmetrically spaced with respect to the axis of that member constrained against any lateral movement. Alternatively, the actuators can be allowed to move laterally while remaining radially aligned with a driven rotor or orbiting stator.

The linear actuators may be sequentially actuated such that force is applied sequentially to said rotor or said orbiting stator at said plurality of locations.

The linear actuators can be of any suitable type such as a solenoid or a pneumatic or hydraulic cylinder. However it is preferred that the linear actuator is a magnetostrictive device or a piezoelectric device.

Ideally there will be no relative slippage between

the surfaces of the rotor and stator. However it is preferred that the motor includes coupling means for providing coupling between the concave and convex surfaces.

The coupling means can take a variety of forms. In one embodiment for example coupling is provided by complimentary engagement means on the stator and rotor. The complimentary engagement means may be gearing, the convex and concave surfaces constituting the pitch diameters of the respective gears. Coupling may also be provided by frictional engagement between the surfaces.

In another aspect this invention resides broadly a method of generating rotary motion, the method including:-

providing a first member having a convex surface and a second member having a concave surface engaging the convex surface, the curvature of the convex surface being greater than the curvature of the concave surface;

fixing one of the members to constitute a stator, and

applying a force to the other member such that the point of engagement between the convex and concave surfaces moves whereby the other member rotates relative to the stator.

In a further aspect this invention resides broadly in a device for converting linear or reciprocating motion into rotary motion, the device comprising:-

a first member having a convex surface;

a second member having a concave surface engaging the convex surface,

wherein the curvature of the convex surface is greater than the curvature of the concave surface such that the convex surface and concave surface engage at a point;

one of the members being non-rotatable and the other of the members being rotatable, and one of the members being driven by an actuator such that the point of engagement between the convex and concave surfaces moves,

whereby one of the members rotates.

In one form, this mechanism can be envisaged as a ring or rotor, forced to rotate around a spigot (internal stator) or inside a drum (external stator) by three or more forces radially or otherwise applied, at three or more points on the rotor at any desired angular spacing.

The force may be applied by any drive means that generates a force and displacement. As indicated above the drive means can include a plurality of actuators. These may remain fixed in their relative positions while being allowed to apply force to the rotor.

The actuators may apply force in sequence and in such a manner as to cause the rotor to roll around the internal stator or inside the external stator. Depending on the sequence and timing of force application, a clockwise or counter-clockwise rotor rotation can be achieved.

The rotor and stator engaging surfaces are preferably circular but could be any suitable shape. A circular rotor will exhibit an eccentric movement as it rotates. The diameter of eccentric movement is the magnitude of the difference in diameter between the rotor and stator.

The apparent gear ratio of the motor is defined as the number of actuator cycles required to turn the rotor one complete turn. The formula for calculating apparent gear ratio is $D/|D-d|$ where D is the diameter of the rotor and d is the diameter of the stator (for all motors).

Description of the Drawings

In order that this invention may be more easily understood and put into practical effect, reference will now be made to the accompanying drawings which illustrate a preferred embodiment of the invention.

FIGS 1, 1A and 2 are cross-sectional elevations of a motor in accordance with the invention having an external rotor ring;

FIGS 3 and 4 schematically illustrate arrangements of the invention which do not utilise an Oldham-type coupling between the drive mechanism and the output shaft to eliminate eccentric movement during rotation;

FIG 5 illustrates force vs angular displacement for an external rotor ring motor having four actuators as illustrated in FIGS 1 and 2;

FIG 6 illustrates force vs angular displacement for a motor with two active actuators spaced 90° apart, and

FIG 7 is a diagram illustrating operation of the motor of FIGS 1 and 2.

Description of Preferred Embodiment of the Invention

As can be seen in FIGS 1 and 2, motor 10 has a housing 11 to which is fixed a mandrel in the form of spigot 12. Base plate 14 to which spigot 12 is attached is fixed relative to housing 11 by screws 13. Spigot 12 has a convex outer cylindrical surface 25. Spigot 12 constitutes the stator of motor 10.

A stepped cylindrical sleeve 15 has an inner concave cylindrical surface 26 of slightly greater diameter than that of spigot 12. Sleeve 15 carries a bearing ring 16 to which inwardly directed forces can be applied by a series of four linear actuators 21. Sleeve 15 is rotatably mounted within housing 11 by means of thrust bearing 19 and an Oldham-type precision coupling 20. Coupling 20 has an output shaft 17 rotatably mounted in housing 11 by bearing assembly 18. Sleeve 15 constitutes the rotor of motor 10.

Linear actuators 21 are mounted mutually at right angles in equidistantly spaced radially directed bores about the periphery of housing 11. Each actuator 21 has a retaining housing 22 in which a coil 24 is located for actuating a centrally positioned magnetostrictive rod 23. Magnetostrictive rod 23 is housed within a tubular sleeve 27 and preloaded by a series of conical spring washers 28. The tubular sleeve may have strain gauges bonded thereto soas to accurately control the force produced by

Actuator 4

$$F_2 \qquad f(\Theta)_2 = \begin{cases} 0 & \text{for } 0<\Theta<\pi \\ -A\sin\Theta & \text{for } \pi\le\Theta\le 0 \end{cases}$$

For the motor to produce torque a lead/lag angle (Φ) must exist between the point of contact of the mating surfaces and the position of the resultant force. The vertex of the angle being the centre of the rotor or orbiting stator.

Torque may be calculated with the aid of FIG 7. Torque produced is equivalent to the resultant force (R) multiplied by the perpendicular distance between the resultant force and the point of contact between the rotor and stator (α)

ie Torque = $R\alpha$ where $\alpha = r\sin\Phi$

thus torque = $R.r\sin\Phi$ where r = radius of the rotor.

Torque is limited by the co-efficient of friction (μ) between the two mating surfaces.

$$\mu = F_f/F_n = \tan\Phi$$

where the mating surfaces are geared F_f/F_n may approach or exceed 1.

In other words, $\tan\Phi$ = tangential force / gear parting force.

The magnitude of Φ and whether the resultant force is leading or lagging with respect to the contact point depends on the direction of motion and the direction of applied torque. Φ may be considered the "hysteresis" of the motor.

Where the motor changes direction the total hysteresis is

$$\Phi_{total} = \Phi_{cw} + \Phi_{ccw}$$
$$= \sin^{-1}(\text{Torque}_{cw}/R.r) + \sin^{-1}(\text{Torque}_{ccw}/R.r)$$

where cw and ccw represent clockwise and counter clockwise directions respectively.

Hysteresis measured at the output equals Φ_{total} / G where G = apparent gear ratio.

An alternative to the method of actuation for all the motors as described above is effected where a motor having four or more equally numbered actuators is operated with half the number of active actuators.

Thus an actuator 180° opposed from an active actuator can be replaced with a spring or a dummy actuator with constant force producing half the maximum force of the active actuator. A constant force spring or actuator is preferably used where the active actuator is controlled sinusoidally, otherwise springs or actuators with linear or non linear characteristics may be used. Force produced by the active actuators with respect to angular displacement is a sine wave where zero force is at the trough and maximum force at its peak.

The force vs angular displacement curve for a motor with two active actuators spaced 90° apart is illustrated in FIG 6.

In use a motor in accordance with this invention can be utilised in wide ranging applications. Applications range from small scale motors for use in clocks, robotics and servomechanisms to heavy industrial applications such as motors for crane winches and the like.

It will be appreciated that motors in accordance with this invention have a number of advantages over known motors. They have infinitesimal angular resolution, do not require a gearbox, are capable of delivering high torque at low RPM and can have zero backlash.

It will of course be realised that whilst the above has been given by way of an illustrative example of this invention, all such and other modifications and variations hereto, as would be apparent to persons skilled in the art, are deemed to fall within the broad scope and ambit of this invention as is herein set forth.

Claims

1. A motor including:
a first member having a convex surface, and
a second member having a concave surface engaging the convex surface;
wherein one of the members constitutes a stator and the other of the members constitutes a rotor, and wherein the curvature of the convex surface is greater than the curvature of the concave surface; and
drive means for driving the rotor such that the point of engagement between the convex and concave surfaces moves whereby the rotor rotates relative to the stator.

2. A motor as claimed in claim 1, wherein said drive means includes a linear actuator for driving the rotor.

3. A motor as claimed in claim 2, wherein said first member is the stator and said second member is the rotor.

4. A motor as claimed in claim 3, wherein said stator is a fixed mandrel and said rotor is a sleeve adapted to rotate about said fixed mandrel.

5. A motor as claimed in claim 1, wherein said second member is the stator and said first member is the rotor.

6. A motor as claimed in claim 5, wherein said stator is a fixed sleeve and said rotor is a sleeve adapted to rotate within said fixed sleeve.

7. A motor as claimed in claim 1, and including damping means for damping eccentric movement of said rotor.

8. A motor as claimed in claim 7, wherein said damping means is an Oldham coupling or the like.

9. A motor as claimed in claim 1, and including constraint means for constraining movement of said stator to a plane perpendicular to the axis of said rotor whereby said rotor does not move eccentrically during rotation and said stator orbits relative to said rotor.

10. A motor as claimed in claim 9, wherein said stator is a sleeve and said rotor is a mandrel adapted to rotate within said sleeve.

11. A motor as claimed in claim 9, wherein said stator is a sleeve and said rotor is a sleeve adapted to rotate about said stator sleeve.

12. A motor as claimed in claim 1, wherein said drive means is adapted to apply force to said rotor at a plurality of locations.

13. A motor as claimed in claim 9, wherein said drive means is adapted to apply force to said orbiting stator at a plurality of locations.

14. A motor as claimed in claim 1, wherein said drive means comprises a plurality of linear actuators.

15. A motor as claimed in claim 14, said drive means comprising at least three linear actuators.

16. A motor as claimed in claim 15, wherein said linear actuators are substantially radially directed and substantially symmetrically spaced relative to said rotor.

17. A motor as claimed in claim 12 or 13, wherein said linear actuators are sequentially actuated such that force is applied sequentially to said rotor or said orbiting stator at said plurality of locations.

18. A motor as claimed in claim 2, wherein said linear actuator is a magnetostrictive device.

19. A motor as claimed in claim 2, wherein said linear actuator is a piezoelectric device.

20. A motor as claimed in claim 1, and including coupling means for providing coupling between said concave and convex surfaces.

21. A motor as claimed in claim 20, wherein said coupling is provided by complimentary engagement means on said stator and rotor.

22. A motor as claimed in claim 16, wherein said complimentary engagement means constitutes gearing.

23. A motor as claimed in claim 20, wherein said coupling is provided by frictional engagement between said surfaces.

24. A method of generating rotary motion, the method including:-

providing a first member having a convex surface and a second member having a concave surface engaging the convex surface, the curvature of the convex surface being greater than the curvature of the concave surface;

fixing one of the members to constitute a stator, and

applying a force to the other member such that the point of engagement between the convex and concave surfaces moves whereby the other member rotates relative to the stator.

25. A device for converting linear or reciprocating motion into rotary motion, the device comprising:-

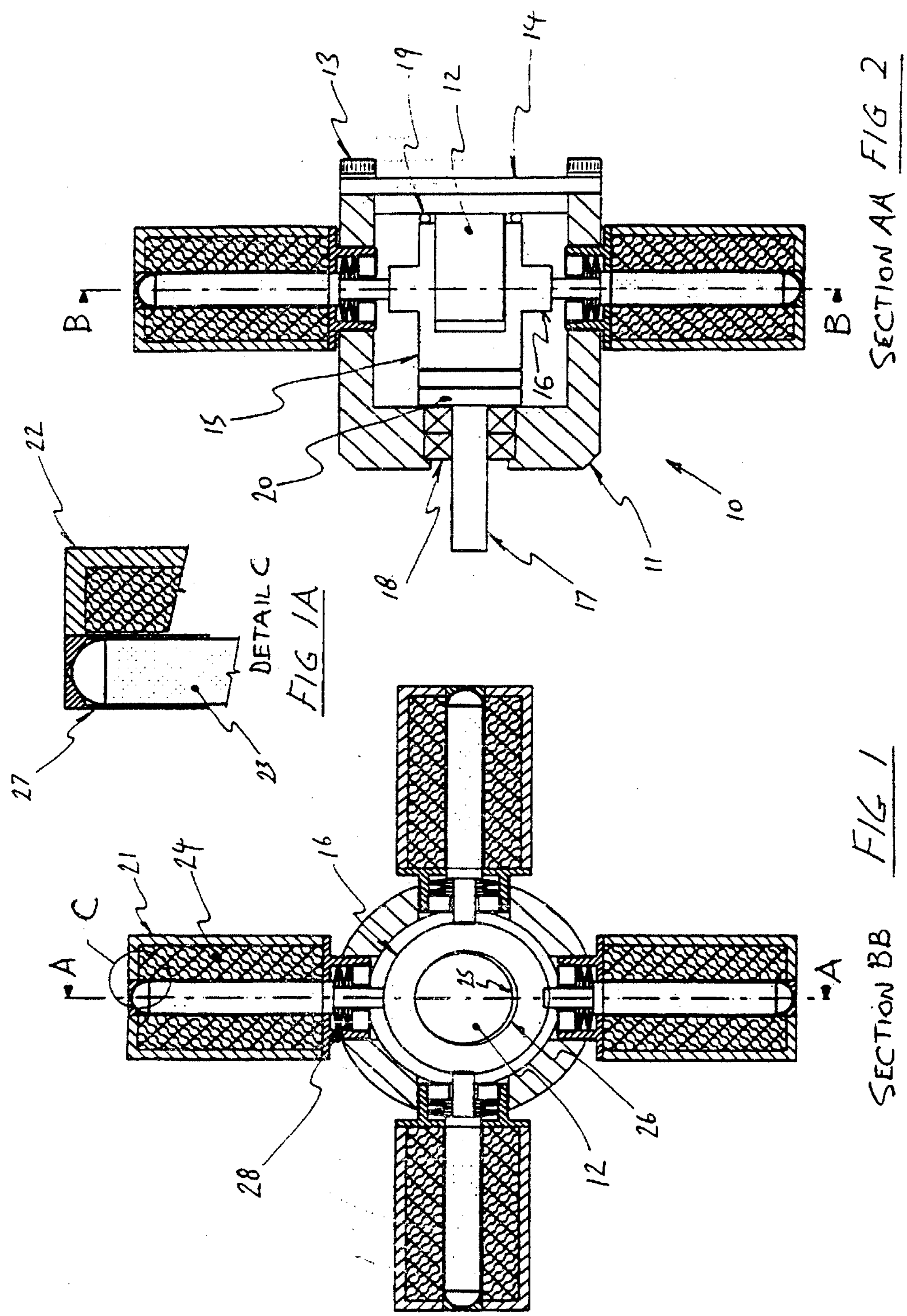
a first member having a convex surface;

a second member having a concave surface engaging

the convex surface,

wherein the curvature of the convex surface is greater than the curvature of the concave surface such that the convex surface and concave surface engage at a point;

one of the members being non-rotatable and the other of the members being rotatable, and one of the members being driven by an actuator such that the point of engagement between the convex and concave surfaces moves, whereby one of the members rotates.



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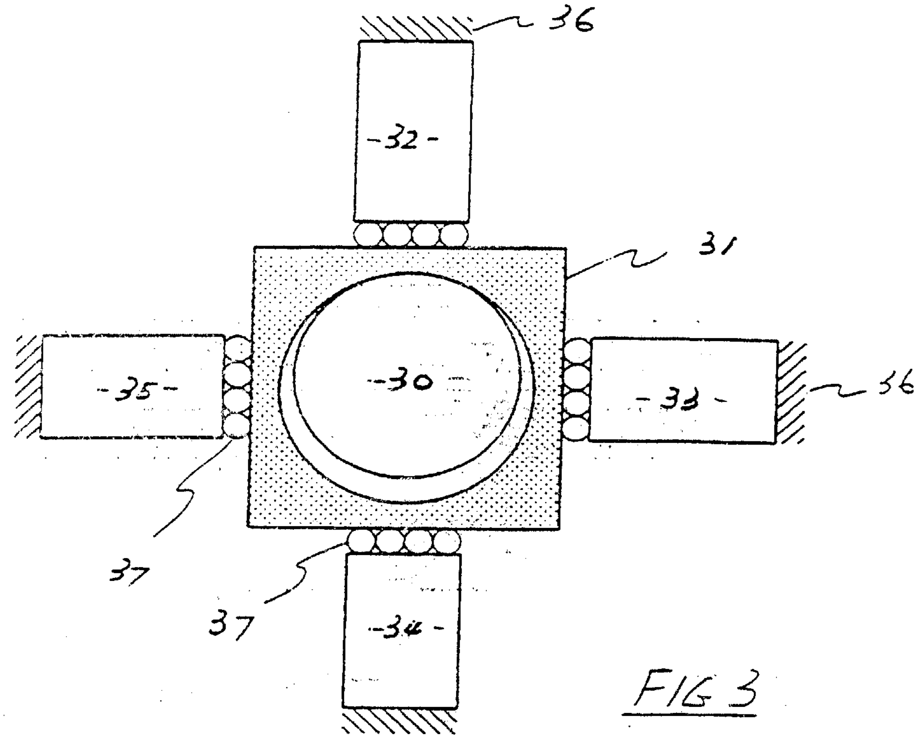


FIG 3

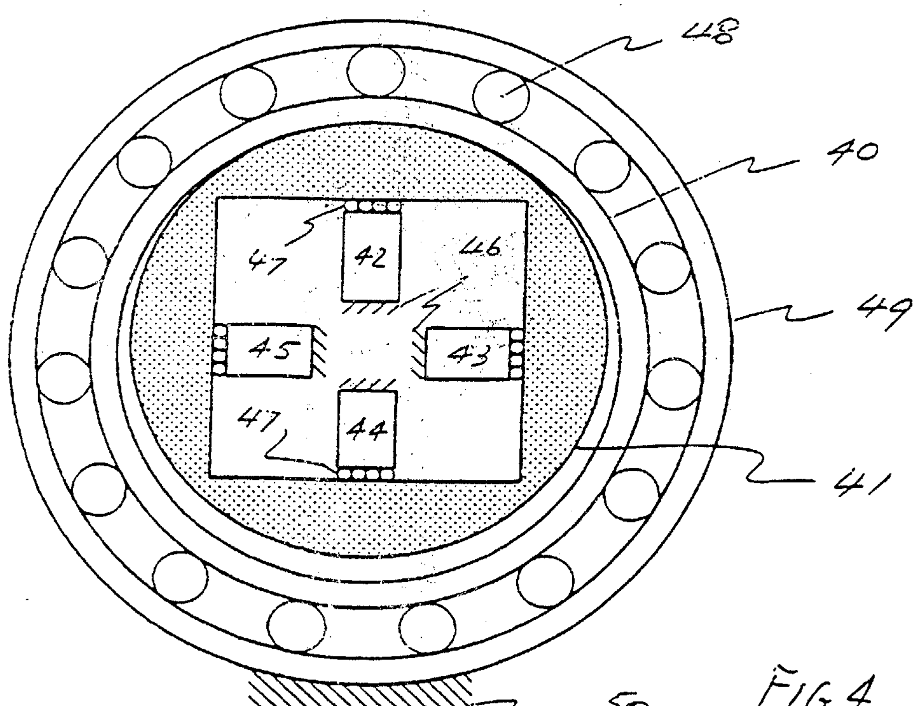


FIG 4

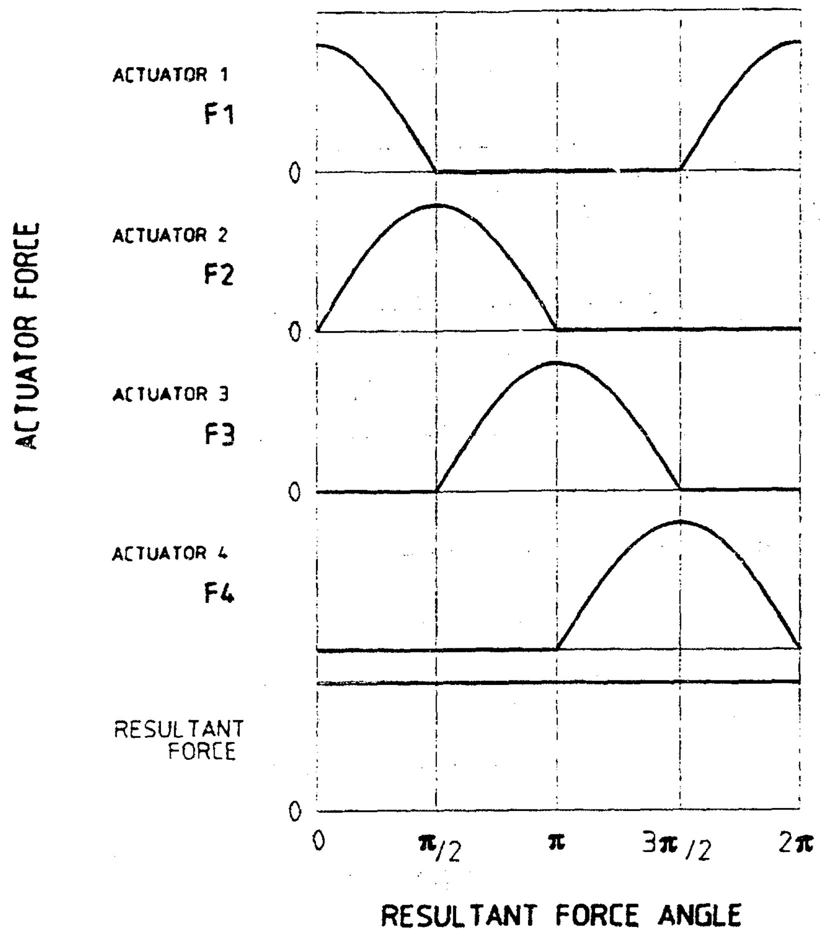

ACTUATOR FORCE
ACTUATOR 1
F1
0
ACTUATOR 2
F2
0
ACTUATOR 3
F3
0
ACTUATOR 4
F4
RESULTANT
FORCE
0
0
π/2
π
3π/2
2π
RESULTANT FORCE ANGLE

FIG. 5

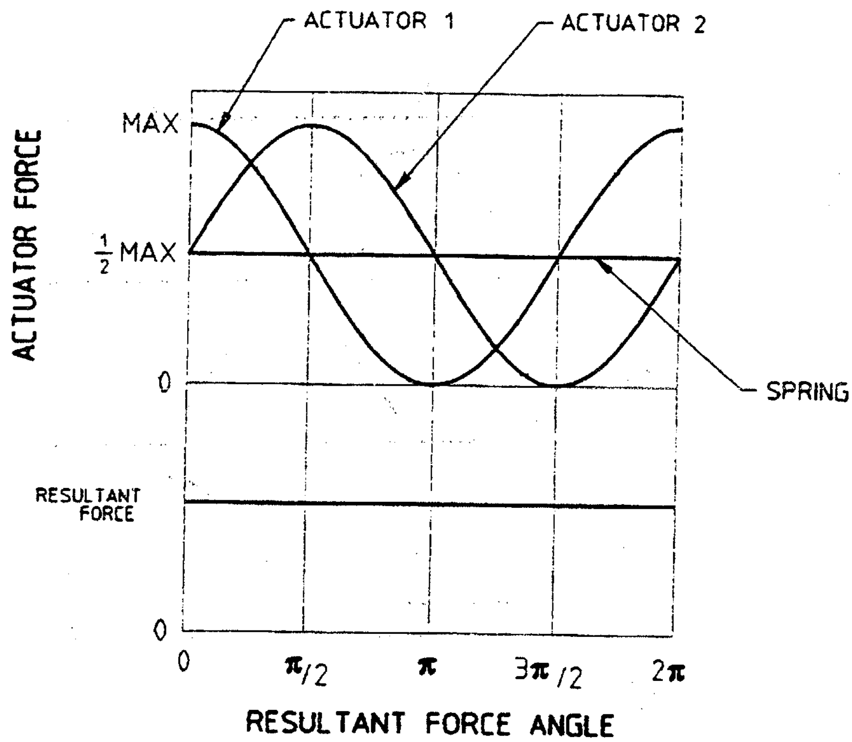
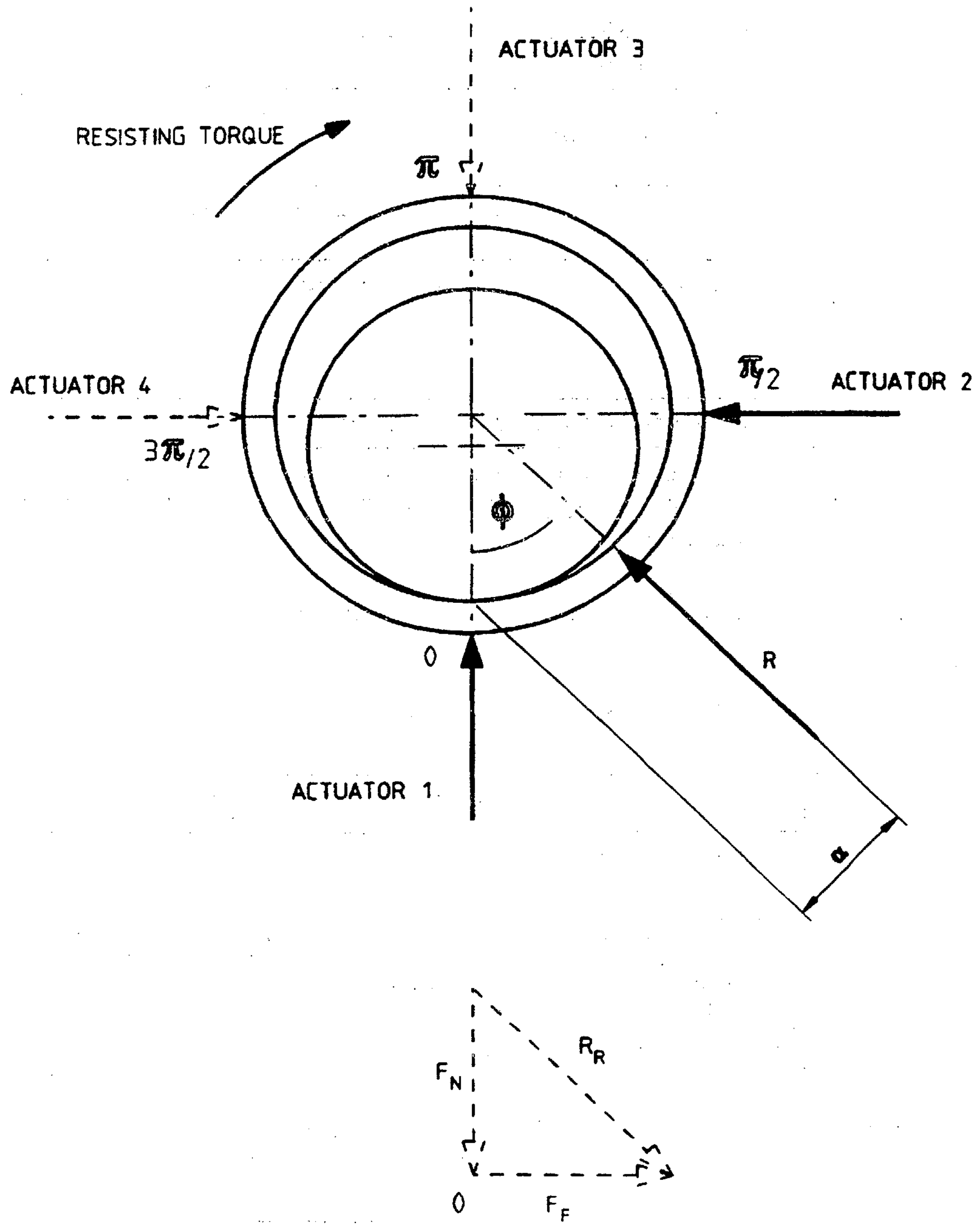

ACTUATOR 1
ACTUATOR 2
MAX
ACTUATOR FORCE
½ MAX
0
SPRING
RESULTANT FORCE
0
0
π/2
π
3π/2
2π
RESULTANT FORCE ANGLE

FIG. 6



REACTION FORCES AT POINT 0

FIG 7

INTERNATIONAL SEARCH REPORT

International Application No.
PCT/AU 97/00026

A. CLASSIFICATION OF SUBJECT MATTER

Int Cl^6: H02N 2/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H02N 2/00, 2/12, 11/00; H01L 41/12

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
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Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	DE 4435996 ** A (BOSCH GmbH ROBERT) 11 April 1996 whole document, in particular Fig 2	1-25
A	US 5465015 A (ANASTAS (et al) 7 November 1995 abstract, figures 3, 4	1, 24, 25
A	US 5053670 A (KOSUGI) 1 October 1991 abstract, figures	1, 24, 25

[X] Further documents are listed in the continuation of Box C

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Date of the actual completion of the international search	Date of mailing of the international search report
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INTERNATIONAL SEARCH REPORT

International Application No.
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C (Continuation)	DOCUMENTS CONSIDERED TO BE RELEVANT	
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A	Patent abstracts of Japan, E-616, page 163,JP, A, 62-293979 * (OLYMPUS OPTICAL CO LTD) 21 December 1987 abstract	1, 24, 25
A	Patent abstracts of Japan, E-1124, page 48, JP, A, 3-169275 * (ETSUTARO OGUCHI) 22 July 1991 abstract	1, 24, 25
A	Patent abstracts of Japan, E-1287, page 41, JP, A, 4-197088 * (NEC CORP.) 16 July 1992 abstract	1, 24, 25
A	Patent abstracts of Japan, E-102, page 22, JP, A, 57-81 * (SOUKICHI MURAKAMI) 5 January 1982 abstract	1, 24, 25
A	Derwent abstract accession No 91-068258, class V06, JP 03-015278 * (SHINSEI KOGYO) 23 January 1991 abstract	1, 24, 25
*	Cited previously in International-type Search.	
**	New citation	

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No.
PCT/AU 97/00026

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Patent Document Cited in Search Report		Patent Family Member			
US	5465015				
DE	4435996				
US	5053670	JP	03164074	JP	03164075
JP	04197088				
JP	57000081				
JP	03015278				
JP	62293979				
JP	03169275				

END OF ANNEX